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BIOPHYSICAL AND PHYSIOLOGICAL EVALUATION OF THE INDIVIDUAL CHEMICAL THREAT AGENT PROTECTIVE PATIENT WRAP

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

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BIOPHYSICAL AND PHYSIOLOGICAL EVALUATION OF THE INDIVIDUAL CHEMICAL THREAT AGENT PROTECTIVE PATIENT WRAP

by

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Air permeability of the chemical threat agent protective patient wrap (WRAP) was reduced by nearly 50% during production compared to the prototype. This study determined if the original recommendations for safe encapsulation time were valid for the production WRAP. Reduced air permeability could affect the thermal properties of the WRAP and the composition of the atmosphere within the WRAP, therefore, a biophysical evaluation of the production WRAP was performed. Biophysical evaluation demonstrated slight differences in thermal and water vapor resistance between the prototype and production WRAPS. However, the capacity for evaporative cooling and the heat strain experienced during encapsulation should not be significantly different between the two WRAPS. Physiologic testing of volunteers during a 6 h encapsulation in the production WRAP, in a comfortable (24°C/20% rh) environment, decreased the mean O_2 concentration 0.9±0.4% and increased CO_2 concentration 0.7±0.2% during the first 15 min of encapsulation and remained stable for the 6 h test. Increased CO_2 concentration was associated with an increased respiratory frequency (f_R). The small decrease observed in O_2 concentration during encapsulation in the production WRAP should not cause any adverse physiologic consequences. CO_2 accumulation could be exacerbated by increased f_R due to patient activity or other conditions known to affect repiration. Further accumulation of CO_2 could result in respiration and metabolic changes that would adversely affect patients in already compromised medical conditions.

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FOREWORD

The timely distribution to the field of newly procured (300 units) chemical threat agent protective patient wraps (WRAP) was dependent upon knowing whether the reduced air permeability and potential modification of the biophysical parameters affecting heat exchange during encapsulation in the WRAP would adversely affect the survivability of the patient. USARIEM was requested by the U. S. Army Medical Materiel Development Activity, Fort Detrick, Frederick, Maryland 21702-5009 (USAMMDA) to conduct this research project for First Article Testing. It was coordinated through MAJ D. Danley, U. S. Army Biomedical Research and Development Laboratory, Fort Detrick, Frederick, Maryland 21702-5010 (USABRDL). The research project also provided information to the contract monitoring agency about future specifications for a scheduled production run for several thousand units.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The air permeability of the chemical threat agent protective patient wrap (WRAP) was reduced by approximately 50% during production (from 8.5 - 12 to 4.8 - 6.1 cubic feet per min per square meter) compared to the developmental prototype WRAP which was originally tested to determine human physiologic limits to encapsulation imposed by environmental extremes. The reduction in air permeability raised questions as to whether the recommendations about encapsulation time made on the basis of the original testing were still valid. The current study determined if the reduction of air permeability in the production WRAP required changes in the recommendations for safe encapsulation time.

Because the reduction in air permeability could potentially affect both thermal properties and the composition of the atmosphere within the WRAP, the study design included a biophysical evaluation of the production WRAP material and a physiologic evaluation of respiratory gases and metabolic measures associated with human volunteers during a 6 h encapsulation. The biophysical evaluation demonstrated very slight differences in thermal and water vapor resistance between the prototype and production WRAPS. Based solely on the water vapor permeability index (i_{mt}) calculated from these evaluations, the capacity for evaporative cooling and the heat strain experienced by patients during encapsulation should not be significantly different in the production WRAP compared to the prototype WRAP originally tested.

Physiologic testing in which volunteers were encapsulated for 6 h in the production WRAP in a comfortable environment (T_a = 24°C; 20% rh) resulted in decreased mean oxygen concentration (O_2) from 20.9 to 20.0(±0.4)% and increased carbon dioxide concentration (CO_2) from 0.04 to 1.10(±0.2)% during the first 15 min of encapsulation. Both remained stable at those levels throughout the 6 h test. The increased CO_2 was associated with an increased respiratory frequency. Additionally, the mean metabolic rate increased from 3.4(± 0.2) to 3.6(± 0.3) ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ after two h of encapsulation.

The potential significance of these results for encapsulated patients can only be estimated from the present data. Breathing 20% O_2 should not cause any adverse physiologic consequences. CO_2 accumulation within the WRAP could be exacerbated by increased respiratory frequency due to activity of the patient or other conditions known

to affect respiration. Further CO_2 accumulation could result in respiratory and metabolic changes that would adversely affect patients in already compromised medical conditions. Those patients will require careful monitoring to detect adverse changes.

INTRODUCTION

The chemical threat agent protective patient wrap (WRAP) is a fabric encapsulation device designed to protect patients from exposure to chemical warfare agents in an operational military environment. The WRAP consists of an impermeable sheet upon which the patient lies and a permeable, carbon impregnated upper sheet through which all air exchange takes place. The two sheets together are designed to completely encapsulate a patient, much like a full sleeping bag zipped over the head, to provide protection from chemical threats. This construction imposes certain functional limitations to encapsulation of patients. Significant potential problems are imposed by the amount of air that can be exchanged through the permeable portion of the WRAP. Limitation of air exchange could impact on the patient's respiratory function and on the insulative qualities which affect the patient's thermoregulatory capacity.

In 1986 USARIEM tested a developmental prototype WRAP to determine safe encapsulation time for healthy subjects in four hot environments which included a simulated solar heat load (1). Air exchange across the tested prototype WRAP was measured as 8.5 - 12 cubic feet per min (cfm) per square meter (2). During initial manufacture (1990) of the WRAP for field distribution (300 units), the mean air permeability was reduced to 4.8 - 6.1 cfm although the materials remained the same as those in the previously tested (1986) WRAP (3). The substantial decrease in air permeability raised questions of impact on respiratory function and thermoregulatory capability that could change the limits to encapsulation time delineated in testing of the prototype WRAP. The present study was designed to address those questions.

STATEMENT OF PURPOSE

There were two purposes to this research. First, the impact of the reduced air permeability of the WRAP on patient respiratory function was evaluated by measuring the oxygen depletion and carbon dioxide accumulation in the WRAP during a 6 h encapsulation period in a comfortable environment (T_a = 24°C; 20% rh). The 6 h encapsulation time was chosen because that was the time of chemical protection of the WRAP, as outlined in the original letter requirement for the WRAP (4,5). A comfortable environment (T_a = 24°C; 20% rh) was chosen to ensure that encapsulation could be

sustained for 6 h without the subjects experiencing heat strain.

The second purpose of this research was to determine whether the heat strain to the patients and safe encapsulation limits in severe environments as measured in the previous study (1) were still valid based on the evaluation of biophysical parameters (dry heat insulative value and the water vapor permeability index) affecting heat exchange during encapsulation in the WRAP.

METHODS

SUBJECTS

Eight young male soldiers (age range 19-22) volunteered to serve as subjects after they were informed of the purpose, procedures, and known risks of this study. Each signed a consent form approved by the USARIEM Human Use Review Committee and the Surgeon General's Human Use Review Office describing the study and its risks. Each subject was evaluated using a history and medical examination before participating in the study. Potential subjects with respiratory, metabolic or psychologic contraindications to encapsulation were excluded from participation. The physical characteristics of the subjects are described in Table 1.

CHEMICAL THREAT AGENT PROTECTIVE PATIENT WRAP

The WRAP was composed of an impermeable ground sheet made of Loretex and nylon and an upper blanket of chemical protective laminated cloth through which respiratory exchange occurred. The shell of the upper blanket was made of a carbon-based core of 3M melt-blown polypropylene covered by Nyco Twill, and was treated with Quarpel. A clear window made of a tri-laminated nylon/saran/polyethylene film was located in the upper blanket where the patient's head was positioned. A cardboard frame was placed inside the WRAP to lift the window off the patient's face.

The air permeability data of the samples of the WRAP used in this study are shown in Table 2. The average air permeability was 5.5 cubic feet per min (cfm) per square foot as determined by the manufacturer (6).

TABLE 1
TEST SUBJECT CHARACTERISTICS

SUBJECT #	HEIGHT (cm)	WEIGHT (kg)	AGE (yr)	A_D[1] (m^2)
1	173	77.8	20	1.9
2	178	61.9	19	2.0
3	191	99.7	21	2.3
4	168	68.3	19	1.8
5	185	76.5	22	2.0
6	183	81.4	22	2.0
7	183	86.5	20	2.1
8	170	64.4	21	1.8
MEAN	179	77	21	2.0
S.D.	8	11	1	0.2

BIOPHYSICAL EVALUATION

To evaluate possible changes in thermal characteristics due to the decreased air permeability of the current production WRAP compared to the prototype WRAP originally tested, the thermal and water vapor resistances of both WRAPS were measured using the Hohenstein Model of Human Skin which was operated in accordance with Deutsches Institut für Normung (DIN) standard 54-101 (7). Samples of test material were manually

[1]DuBois body surface area

cut from the upper blanket of each WRAP. The sample from the prototype WRAP had been exposed to actual human physiological test conditions, while the sample of the current WRAP was not previously used (WRAP # 4; Table 2).

TABLE 2
INDIVIDUAL CHEMICAL THREAT AGENT PROTECTIVE PATIENT WRAP
AIR PERMEABILITY DATA (3)

WRAP (#)	AIR PERMEABILITY (MEAN±SD) (cfm)	SAMPLES TESTED (#)
1	5.4 ± 0.1	9
2	5.7 ± 0.2	6
3	6.1 ± 0.2	6
4	5.6 ± 0.3	6
5	5.6 ± 0.5	6
6	5.5 ± 0.2	6
7	6.0 ± 0.3	9
8	5.8 ± 0.5	9
9	5.8 ± 0.5	6
10	5.6 ± 0.2	6

The thermal resistance (R_{ct}), according to the DIN standard represents a quantity specific to a textile material in a given environment which determines the "dry" heat flux (composed of conduction, convection and radiation) passing through the material in a steady-state condition effected by a temperature gradient perpendicular to the materials' surface area. The water vapor resistance (R_{et}) is the quantity which determines the "latent" or evaporative heat flux (composed of diffusion and convection) passing through the material effected by a partial pressure gradient perpendicular to the materials' surface.

R_{ct} and R_{et} were used to calculate the water vapor permeability index (i_{mt}) which the DIN standard defines as the ratio of thermal to water vapor resistance of a textile layer according to the following equation:

$$i_{mt} = S \cdot (R_{cl} \cdot R_{et}^{-1})$$

where $S = 0.6$ millibar$\cdot K^{-1}$

The i_{mt} index is a unitless value between 0 (for a water vapor impermeable textile layer) and 1. A value of $i_{mt} = 1$ would theoretically mean that the textile layer had only the resistance of a layer of air the same thickness as the textile itself. A high i_{mt} value is desired for increasing thermal comfort of soldiers enclosed in chemical protective garments.

PHYSIOLOGIC EVALUATION

The primary purpose of the physiologic evaluation was to determine the effect of the reduced air flow on the respiratory function of the subjects as reflected by the concentrations of oxygen and carbon dioxide within the WRAP during a 6 h encapsulation. Additionally, heart rate, respiratory frequency, tidal volume and rectal temperature were measured, and certain metabolic parameters (oxygen uptake, carbon dioxide production, and respiratory exchange ratio) were calculated.

Test Subject Familiarization and Requirements

All subjects were familiarized with the test procedures, including encapsulation in the WRAP, before they participated in the study. The subjects refrained from drinking alcoholic beverages the previous 24 h and coffee or soft drinks containing caffeine for 8 h prior to the experiments and fasted overnight.

Experimental Procedures and Environmental Conditions

Experiments began at 0700 h and two subjects were studied during each experiment. The subjects were dressed in gym shorts and a T-shirt for the experiment rather than the BDU because medics at a Battalion Aid Station would cut off the contaminated BDU. After each subject inserted a previously calibrated YSI thermistor to a depth of 10 cm past the anal sphincter, ECG electrodes were applied for subsequent heart rate measurement (Hewlett-Packard telemetry). Body weight was measured (SECA balance)

prior to entering the environmental chamber (T_a = 24°C; 20% rh). The subjects then lay on the ground cover of the WRAP which was placed on a standard Army litter inside the environmental chamber. A small diameter tube was taped between the eyebrows and oxygen (FIO_2) and carbon dioxide ($FICO_2$) concentrations within the WRAP were monitored continuously in 250 ml of air sampled per min from the WRAP (Sensormedics 2900). Rectal temperature (T_{re}) was monitored frequently until it was stable (30 - 40 min). After 15 min of rest, resting metabolic rate was measured (Sensormedics 2900).

When T_{re} stabilized, that time was designated 0 time and the upper blanket was positioned over the test volunteer in preparation for encapsulation. FIO_2, $FICO_2$, heart rate, and respiratory frequency (f_R) were measured immediately before the WRAP was zipped up to complete encapsulation and the 6 h experiment began.

During the first 15 min of encapsulation, oxygen and carbon dioxide concentrations within the WRAP and heart rate were measured each min. FIO_2 and $FICO_2$ were measured each min for the next 30 min at which time the frequency of measurement was decreased to 5 min, although the gas concentrations were monitored continuously. T_{re} was measured every five min and respiratory frequency was measured at 15 min intervals throughout the encapsulation. After two hours of encapsulation metabolic rate was measured again. After 6 h, the encapsulation ended, then the body weight was measured again.

To help alleviate boredom during the 6 h of encapsulation, subjects were permitted to watch previously recorded movies through the WRAP window.

Data Analysis

FIO_2, $FICO_2$, heart rate, respiratory frequency and rectal temperature were compared during the 6 h encapsulation period using a one-way analysis of variance with repeated measures. Oxygen uptake, carbon dioxide production, respiratory exchange ratio and tidal volume were compared before and after 2 h of encapsulation using a one-way analysis of variance with repeated measures.

RESULTS AND DISCUSSION

BIOPHYSICAL EVALUATION

Table 3 shows the biophysical parameters for the prototype WRAP sample from the previous study and the production WRAP sample. The biophysical evaluations of the prototype WRAP used in the 1986 study (1) and the production WRAP indicate that there are very slight differences in thermal and water vapor transmission between the two samples. Note that the water vapor permeability index was approximately 7% less and the thermal resistance was about 10% greater in the production WRAP compared to the prototype WRAP. This may be due to actual material differences or simply that the

TABLE 3
THERMAL RESISTANCE (R_{cl}), WATER VAPOR RESISTANCE (R_{el}), AND WATER VAPOR PERMEABILITY INDEX (i_{mt})

	R_{cl} ($m^2 \cdot K \cdot W^{-1}$)	R_{el} ($m^2 \cdot mbar \cdot W^{-1}$)	i_{mt}
Prototype WRAP	0.038 (0.245 clo)	0.085	0.27
Production WRAP	0.042 (0.271 clo)	0.102	0.25
Difference (%)	10%	20%	-7%

current production WRAP is slightly thicker than the prototype WRAP used in 1986. Based solely on the resulting water vapor permeability indices (i_{mt}) calculated from these evaluations, the capacity for evaporative cooling should be similar in both WRAPS. The biophysical data indicate that heat strain experienced by volunteers during encapsulation should not be different between the two WRAPS. Consequently, the safe encapsulation time limits determined previously (1) should not be substantially different during encapsulation in the production WRAP.

PHYSIOLOGIC EVALUATION

Fig. 1 shows the mean oxygen and carbon dioxide concentrations for six subjects during the first 45 min of encapsulation. F_IO_2 decreased over the first 15 min of encapsulation, then stabilized for the rest of the 6 h encapsulation period. Fig. 1 also shows that F_ICO_2 increased during the initial 15 min of encapsulation before stabilizing for the remainder of the encapsulation period. F_IO_2 and F_ICO_2 data for the individual subjects are presented in Figs. 2-5. With the exception of Subject 6, there was very little variation in these responses. F_IO_2 averaged 20.0(±0.4)% and F_ICO_2 averaged 1.1(±0.2)% during the 6 h encapsulation period. F_IO_2, when stabilized to 20%, should not pose any physiologic consequence to the patient. However, F_ICO_2 stabilized to about 1.1% which may have resulted in the slightly greater respiratory frequency, perhaps reflecting changing metabolism, at the end of the encapsulation period (see below). Increases in respiratory frequency due to activity or other conditions related to traumatic wounds may further raise CO_2 within the WRAP.

We were concerned that our method of measuring oxygen and carbon dioxide concentrations within the WRAP (aspirating 250 ml of air per min from the WRAP and measuring F_IO_2 and F_ICO_2) would affect the diffusion of oxygen and carbon dioxide across the WRAP. In order to determine the effect of aspirating 250 ml of air per min from the WRAP on F_IO_2 and F_ICO_2, a pilot study was conducted on one subject. During the 1 h encapsulation period, aspiration was stopped for 10 min after 20 min of encapsulation (Fig. 6). Aspiration was restarted after 30 min of encapsulation so that F_IO_2 and F_ICO_2 could be measured for the next 10 min. Aspiration was then interrupted for about 20 min before F_IO_2 and F_ICO_2 was measured again. Fig. 6 shows that F_IO_2 and F_ICO_2 were not affected by aspirating 250 ml of air per min out of the WRAP. That is, oxygen concentration did not decrease more and carbon dioxide did not build up to a greater extent within the WRAP when aspiration was interrupted for up to 20 min.

Metabolic rate averaged 3.4(± 0.2) ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ before encapsulation and increased to 3.6(± 0.3) ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ after two h of encapsulation (Table 4; $p = 0.01$). Resting metabolism is generally defined as 3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ for an average young adult. The present data indicate that the subjects were relaxed while participating in the experiment. It seems possible that a nonsedated wounded individual could have a higher

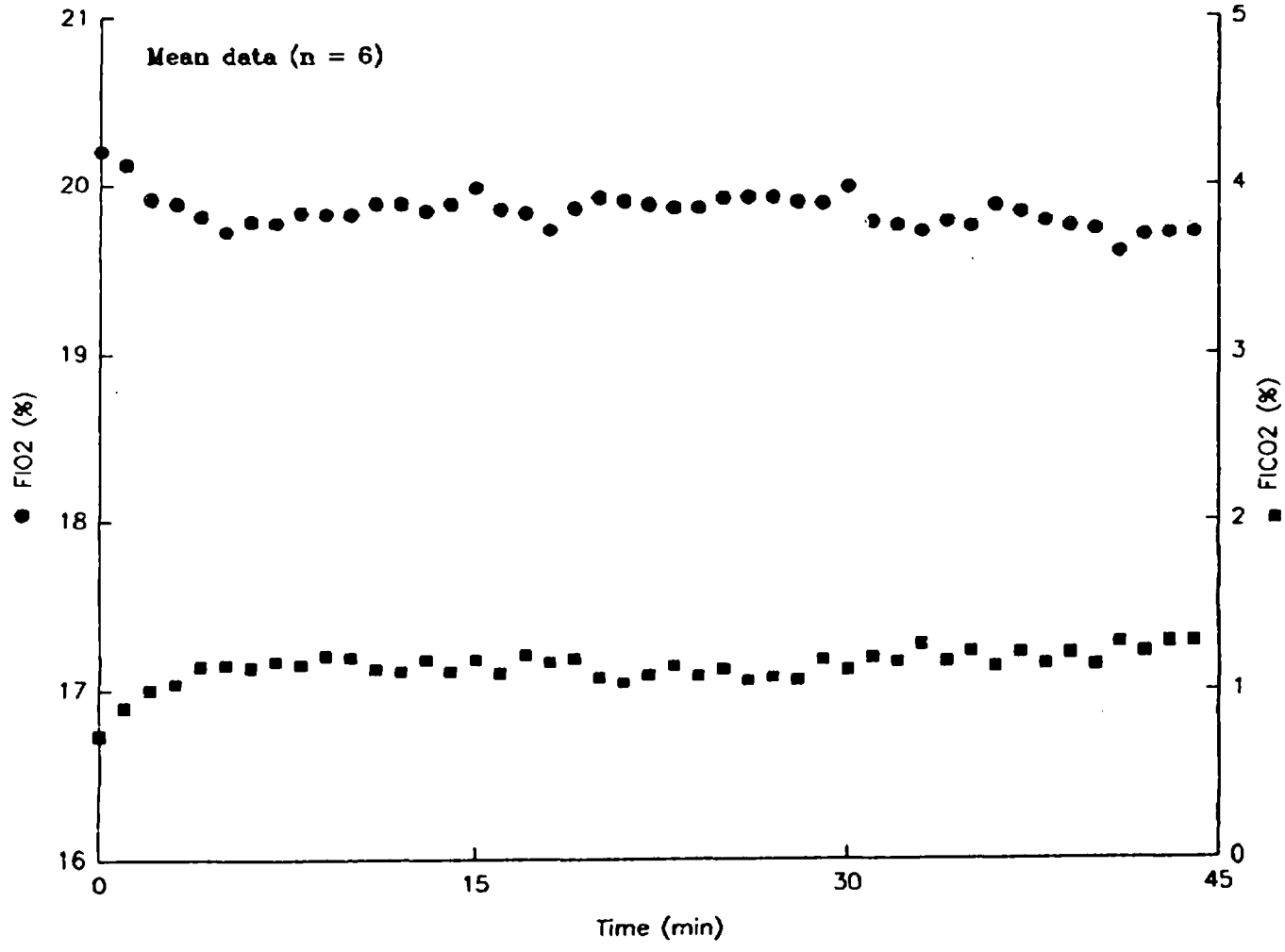

Figure 1 Mean (n=6) FIO_2 and $FICO_2$ Within the Protective Patient Wrap During Initial Forty-five Min of Encapsulation.

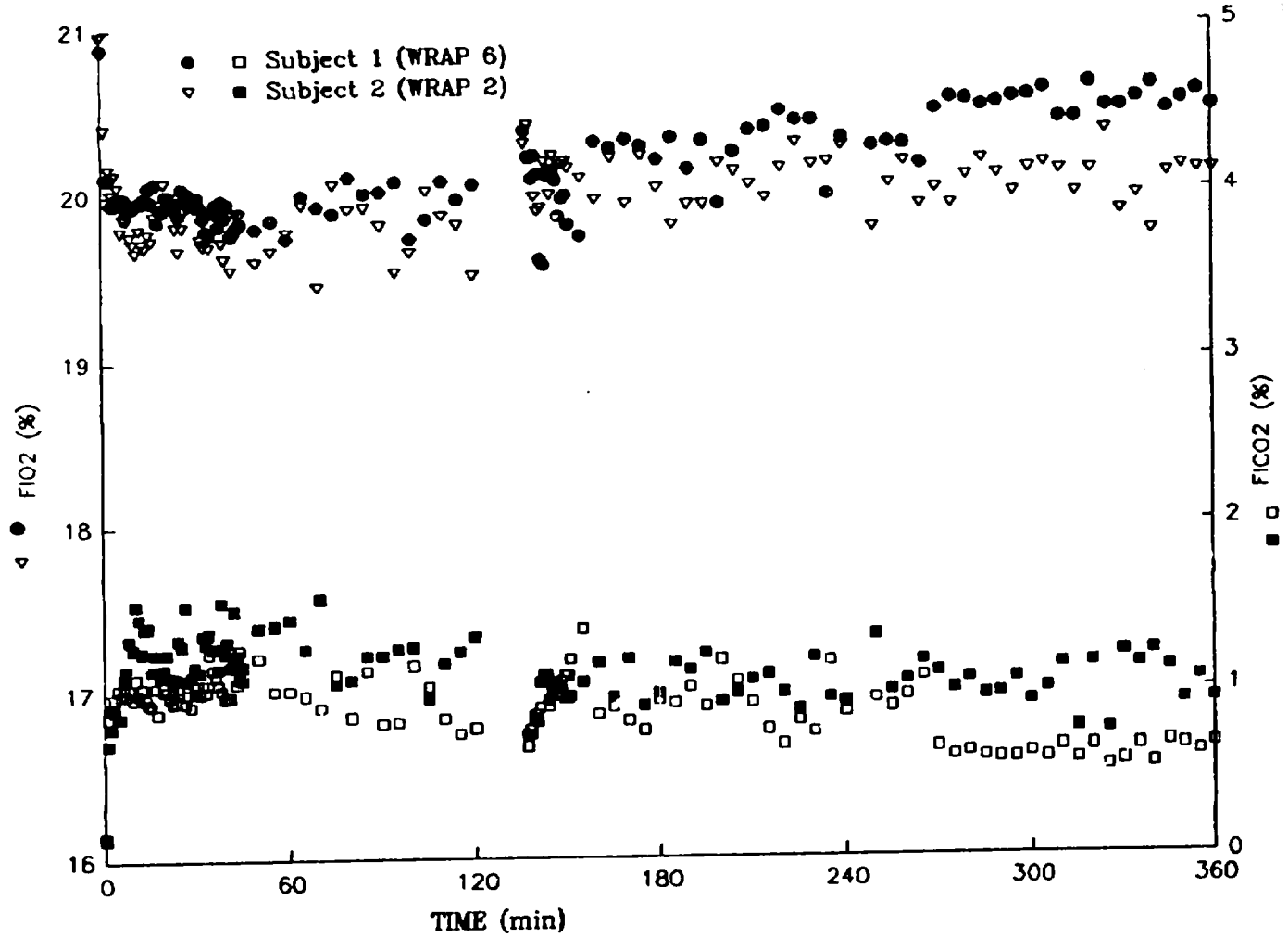

Figure 2 F_{IO_2} and F_{ICO_2} Within the Protective Patient Wrap For Subjects 1 and 2 During 6 h Encapsulation.

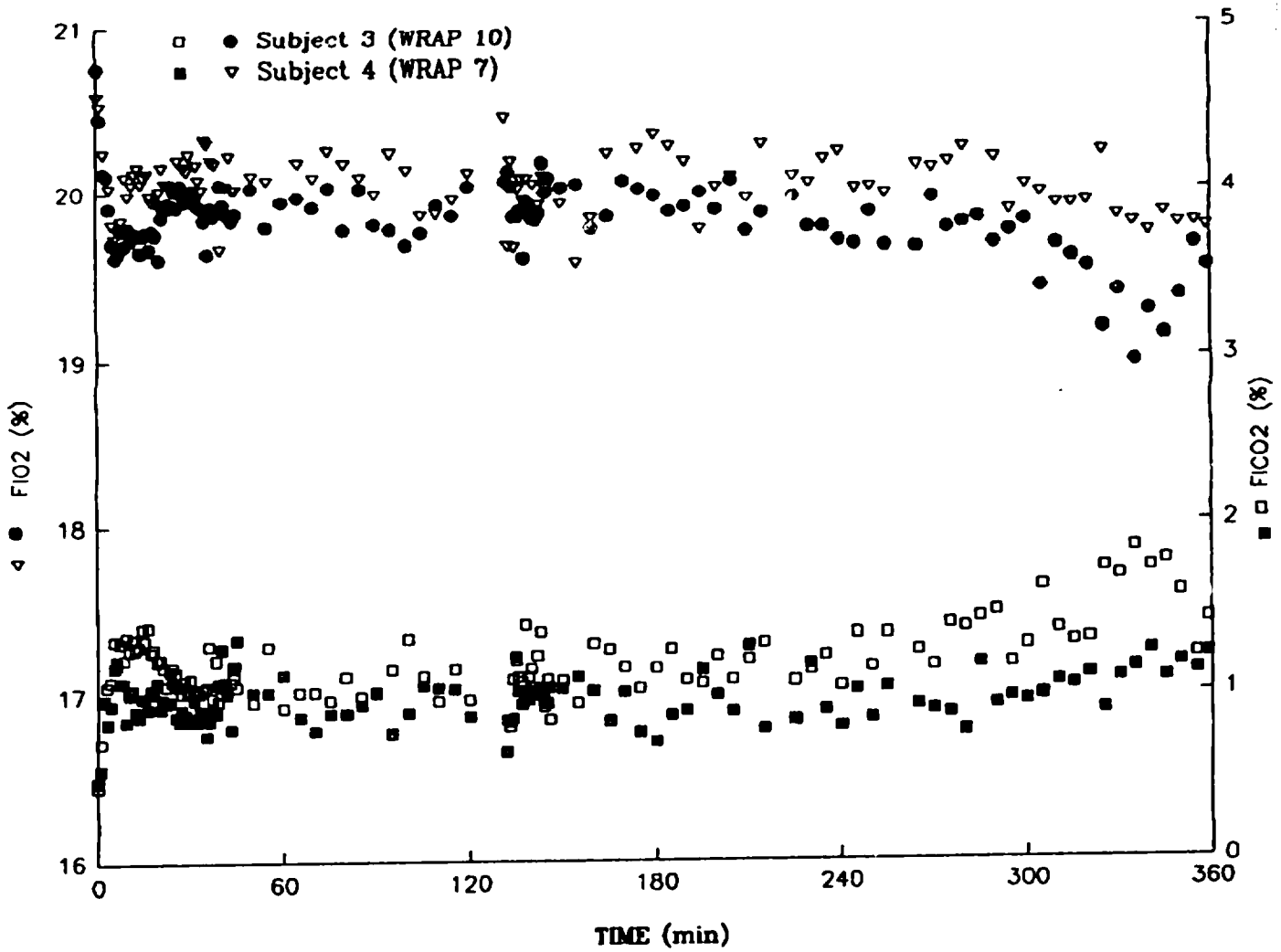

Figure 3 F_{IO_2} and F_{ICO_2} Within the Protective Patient Wrap For Subjects 3 and 4 During 6 h Encapsulation.

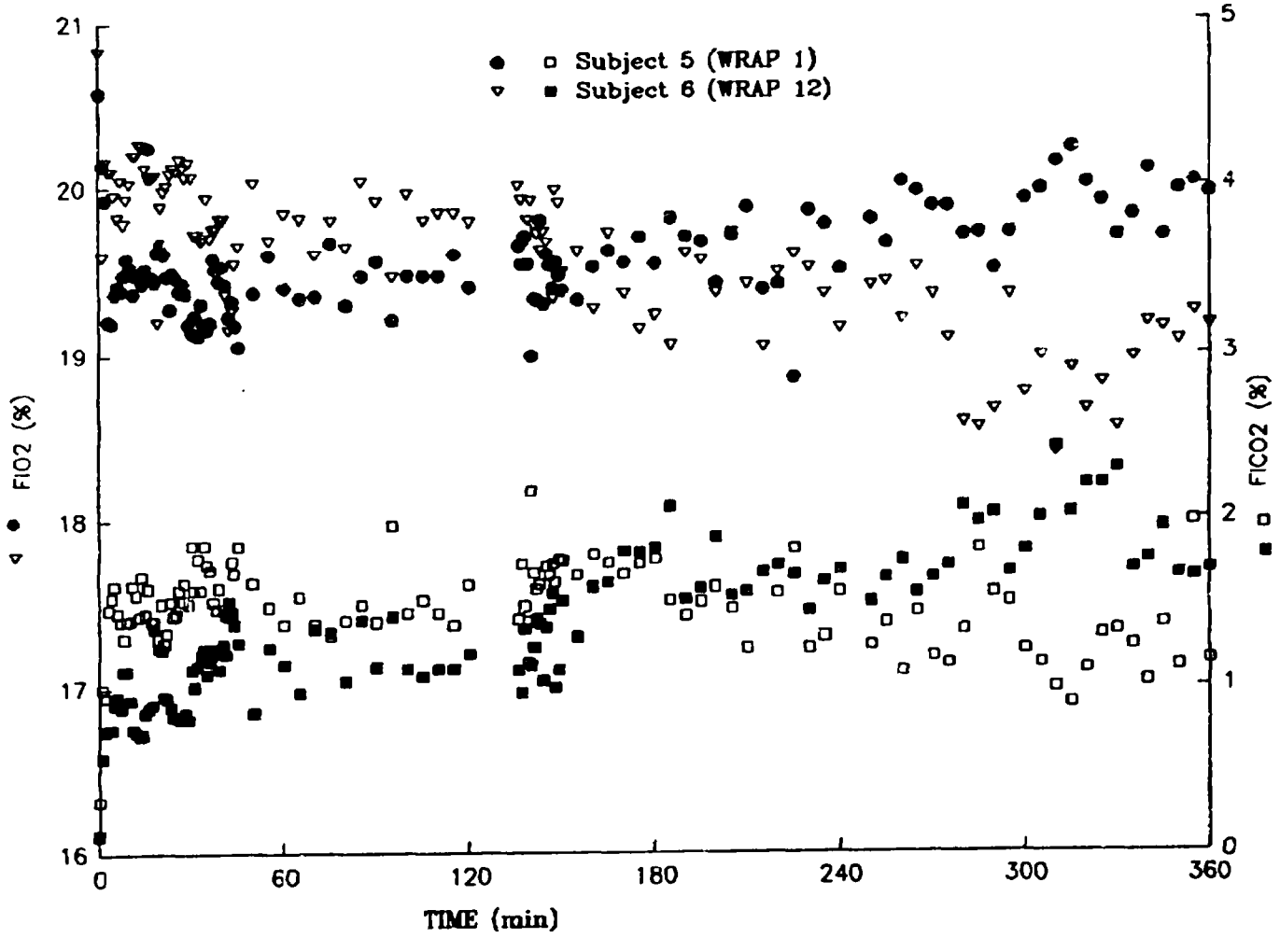

Figure 4 F_{IO_2} and F_{ICO_2} Within the Protective Patient Wrap For Subjects 5 and 6 During 6 h Encapsulation.

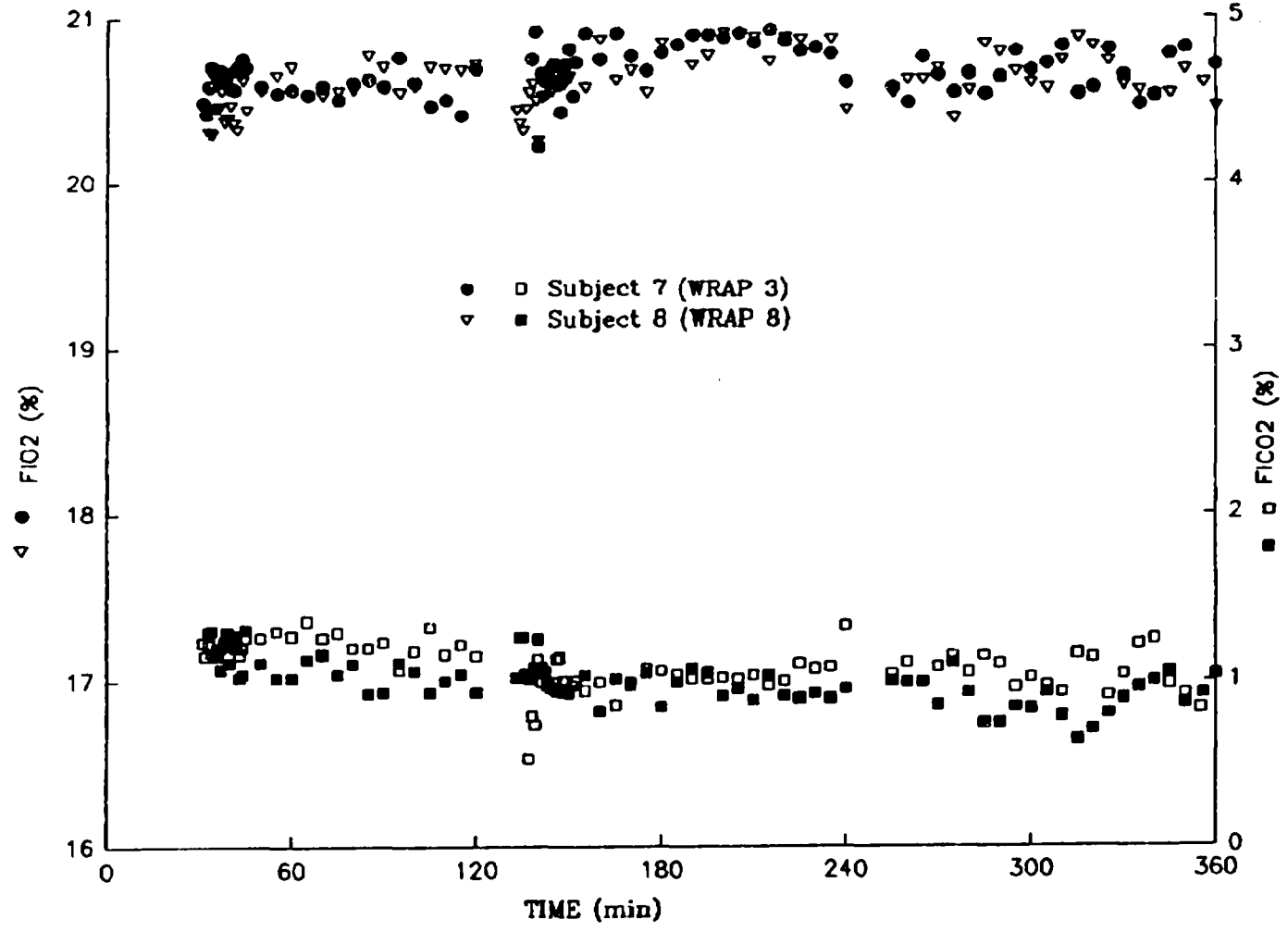

Figure 5 FIO_2 and $FICO_2$ Within the Protective Patient Wrap For Subjects 7 and 8 During 6 h Encapsulation.

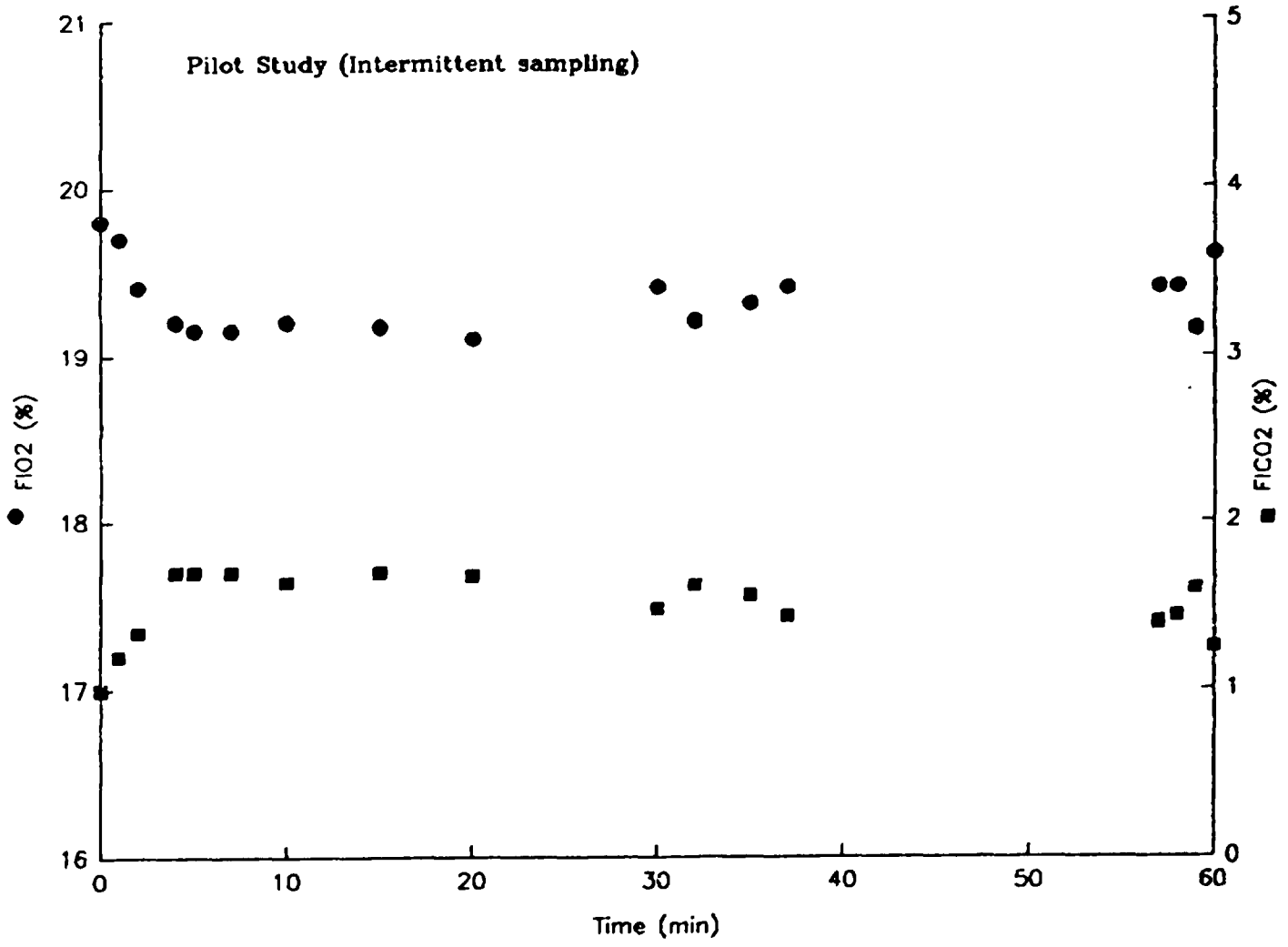

Figure 6 F_{IO_2} and F_{ICO_2} Within the WRAP Determined By Intermittent Air Sampling During 1 h Encapsulation.

metabolic rate. Carbon dioxide production, respiratory exchange ratio and tidal volume were not significantly different between the two times (Table 4).

TABLE 4

OXYGEN UPTAKE ($\dot{V}O_2$), CARBON DIOXIDE PRODUCTION ($\dot{V}CO_2$), RESPIRATORY EXCHANGE RATIO (R) AND TIDAL VOLUME (V_T) BEFORE AND AFTER 2 H OF ENCAPSULATION IN THE WRAP

SUBJECT (#) (l)	$\dot{V}O_2$ (ml $O_2 \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}CO_2$ (ml $CO_2 \cdot kg^{-1} \cdot min^{-1}$)	R	V_T
		BEFORE ENCAPSULATION		
1	3.59	3.34	0.93	0.57
2	3.63	3.25	0.90	0.57
3	3.01	2.62	0.88	0.67
4	3.67	3.08	0.84	0.47
5	3.50	2.98	0.85	0.76
6	3.18	2.76	0.87	0.58
7	3.28	2.39	0.73	0.54
8	3.45	2.97	0.87	0.52
		2 h ENCAPSULATION		
1	3.78	3.93	1.04	0.58
2	3.73	3.18	0.86	0.54
3	3.18	2.91	0.92	0.83
4	3.95	3.16	0.80	0.52
5	3.56	3.07	0.87	0.69
6	3.21	2.66	0.83	0.56
7	3.28	3.02	0.93	0.72
8	3.79	2.95	0.78	0.46

The increased metabolic rate two hours after encapsulation may be explained by the normal circadian variation in heat production (8) and also might indicate slight subject discomfort as the encapsulation period proceeded. After 2 h of encapsulation $\dot{V}CO_2$, tidal volume and respiratory exchange ratio were not different from pre-encapsulation values. Apparently, the 1% increase in F_ICO_2 for the 100 min prior to metabolic rate measurement did not significantly affect carbon dioxide output. Also, the increased F_ICO_2 at 2 h of encapsulation was not associated with any respiratory compensatory mechanisms to lower the arterial partial pressure of carbon dioxide which would affect tidal volume or pulmonary ventilation as evidenced by the ventilatory equivalent of oxygen or the respiratory exchange ratio.

We made infrequent metabolic measurements because the technique required that the exhaled air be exhausted from the WRAP so that the volume, oxygen concentration and carbon dioxide concentration could be measured. Consequently, F_IO_2 and F_ICO_2 approached room air during metabolic rate measurement. We sought to minimize this artificial condition within the WRAP by only measuring metabolic rate once during the encapsulation. The technical necessity of continuously aspirating a small volume of air from the WRAP did not affect F_IO_2 and F_ICO_2 as shown in the pilot study (Fig. 6).

Figs. 7-10 show respiratory frequency, rectal temperature and heart rate for the individual subjects during 6 h of encapsulation. Respiratory frequency increased after encapsulation in seven of the eight subjects with the average increase from pre-encapsulation to 359 min of encapsulation was 3±3 breaths•min^{-1}. Rectal temperature increased gradually in five subjects during encapsulation while rectal temperature did not change consistently in the other three subjects. The variation in T_{re} may be explained by two factors, circadian periodicity in core temperature (9) and the effect of drowsiness on core temperature (10). In five of the subjects rectal temperature gradually increased over the encapsulation period which is the normal circadian response. In the remaining three subjects, T_{re} dropped at different times during the encapsulation and may have been associated with drowsiness of the test subject.

Heart rate did vary during the encapsulation but was not correlated with encapsulation time. Time of encapsulation did not affect heart rate responses as can be seen in Figs. 7-10. The large variability in heart rate was most likely due to individual

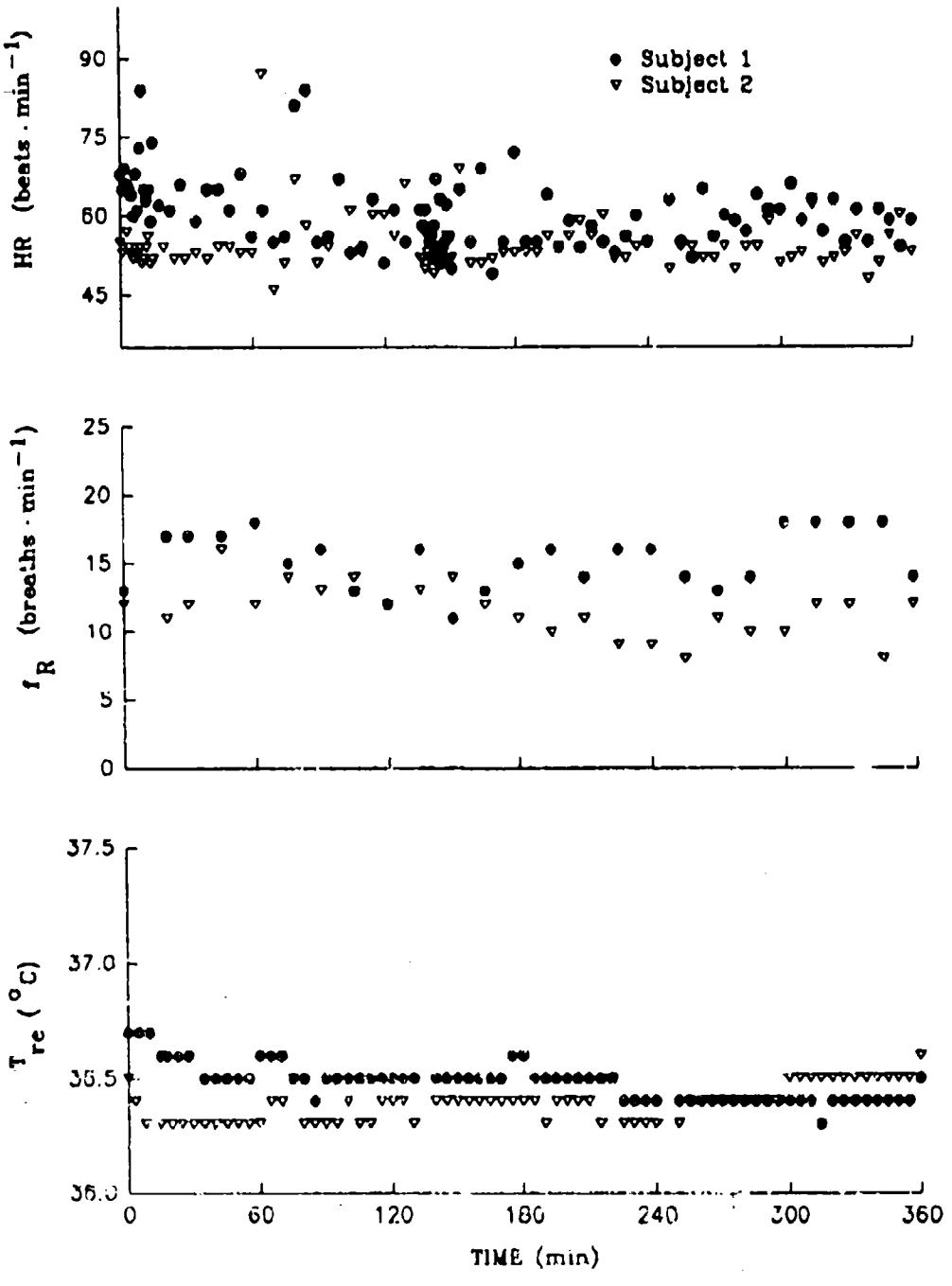

Figure 7 Heart Rate (HR), Respiratory Frequency (f_R) and Rectal Temperature (T_{re}) For Subjects 1 and 2 During 6 h Encapsulation.

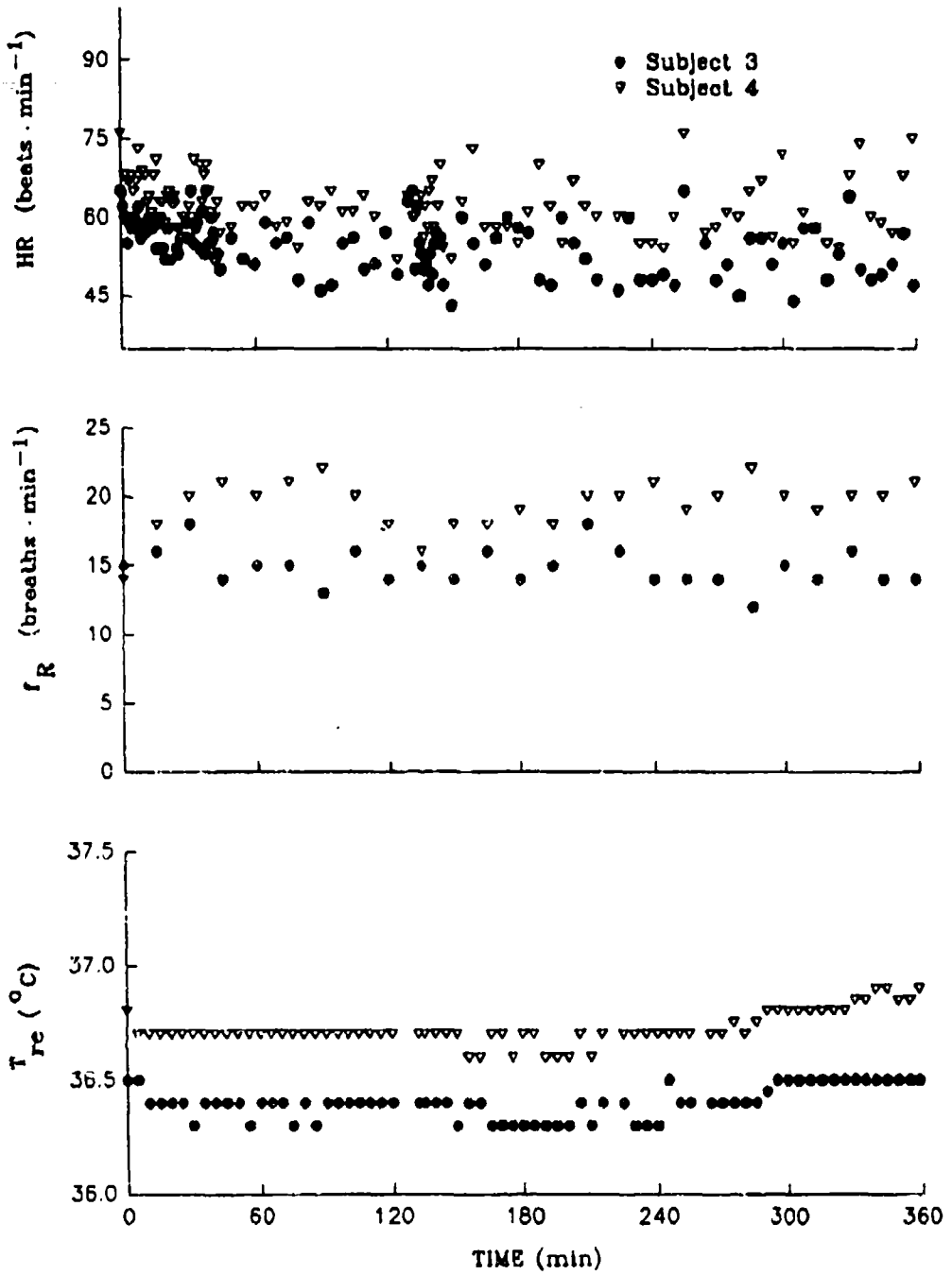

Figure 8 Heart Rate (HR), Respiratory Frequency (f_R) and Rectal Temperature (T_{re}) For Subjects 3 and 4 During 6 h Encapsulation.

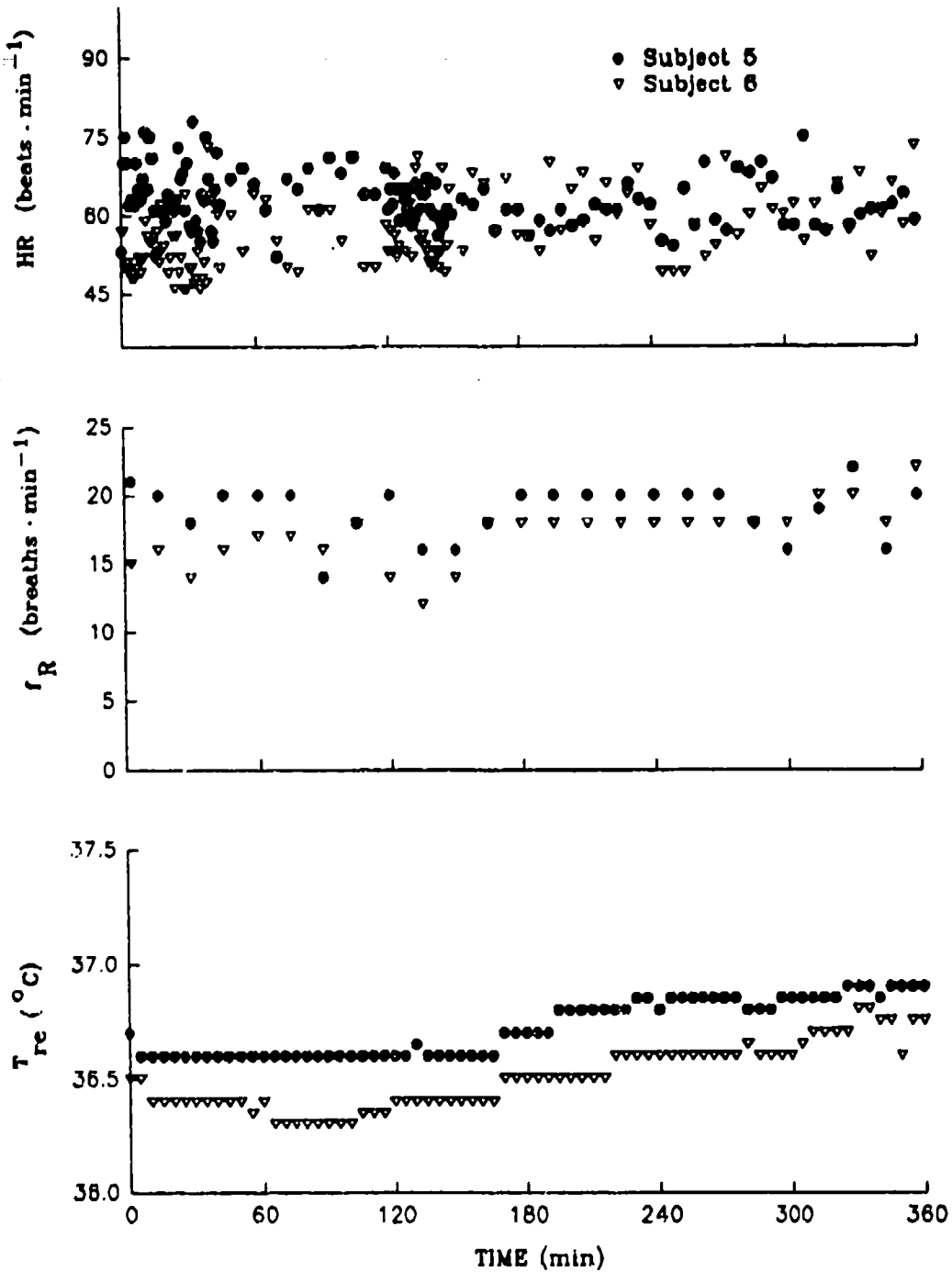

Figure 9 Heart Rate (HR), Respiratory Frequency (f_R) and Rectal Temperature (T_{re}) For Subjects 5 and 6 During 6 h Encapsulation.

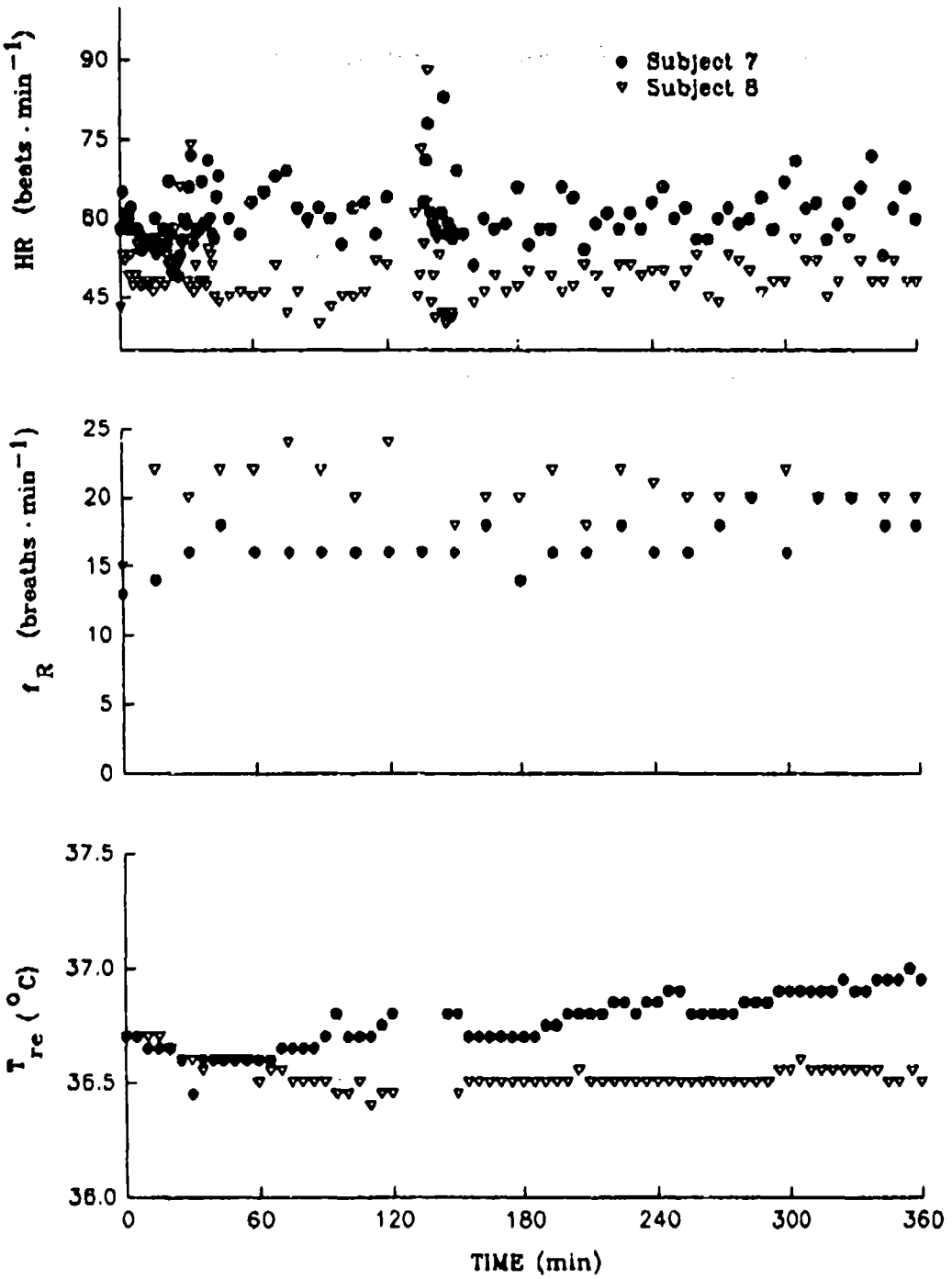

Figure 10 Heart Rate (HR), Respiratory Frequency (f_R) and Rectal Temperature (T_{re}) For Subjects 7 and 8 During 6 h Encapsulation.

subject's reaction to the movies being shown to alleviate boredom during 6 h of encapsulation.

The change in body weight averaged 0.8(±0.4) $g \cdot min^{-1}$ during encapsulation. The water loss reflected in the measured body weight changes included both insensible perspiration, sweating and respiratory water loss. The body weight changes observed indicate that sweating was not substantial during encapsulation in the environment studied. This observation reinforces the conclusion drawn from the rectal temperature data that there was no heat strain experienced by the subjects during encapsulation in such a comfortable environment.

CONCLUSIONS

This evaluation demonstrated that the decrease in air permeability in the current production WRAP compared to the previously tested prototype WRAP may affect certain biophysical and physiological parameters, some of which may impact on safe encapsulation time. Biophysical evaluation showed very slight differences between the two WRAPS in measured thermal and water vapor resistances. Based solely on the resulting calculated water vapor permeability indices (i_{m}), the capacity for evaporative cooling and heat strain should be similar between the two WRAPS. Consequently, the safe encapsulation time limits determined in the prototype WRAP should not be substantially different during encapsulation in the current WRAP.

Encapsulation in the production WRAP resulted in a decrease in oxygen concentration of the air within the WRAP from approximately 21 to 20% and an increase in the carbon dioxide concentration from approximately 0.03 to 1%. These concentrations remained stable during a 6 h encapsulation in a comfortable thermal environment. The slight decrease in oxygen concentration would not be expected to have a significant physiologic effect on patients encapsulated within the WRAP. The increase in carbon dioxide had little effect in this study which involved healthy soldiers. The accumulation of carbon dioxide within the WRAP could be exacerbated by increased metabolism or

hyperventilation due to patient activity or stimulation from pain or altered metabolism. Further accumulation of carbon dioxide could effect metabolic and/or respiratory compensation and alter safe encapsulation time.

RECOMMENDATIONS

The volunteers tested in this study were healthy, well-hydrated soldiers and the experiments were conducted in a comfortable environment. Casualties of war are a different population in regard to their medical and physiologic status than the soldiers studied in this laboratory. It must be noted that any condition or drug which affects patients' thermoregulation or cardiovascular/pulmonary status may decrease safe encapsulation time compared to the healthy soldiers tested here. Conditions might include hyperthermia, pre-treatment and antidotal treatment drugs for chemical poisoning, dehydration and blood loss.

Six hours of encapsulation was easily tolerated in the comfortable environment in which this study was conducted. The biophysical evaluation comparing the current production WRAP with the prototype WRAP used in the previous study (1) indicated that encapsulation in either of the two WRAPS would result in similar heat strain to the patient. Therefore, it is recommended that the safe encapsulation limits determined previously (1) in four hot environments which included simulated solar heat loads be applied to the current production WRAP. Those limits are listed in the Appendix.

The limits to encapsulation imposed by alteration of respiratory gas exchange through the current production WRAP are dependent on the respiratory and metabolic status of the patient. Uncompromised patients should be able to tolerate a 6 h encapsulation in the comfortable environmental conditions tested here. Patients with increased metabolism or hyperventilation cannot be expected to tolerate encapsulation for as long a period of time. Those patients will have to be monitored carefully and the length of encapsulation or the conditions of encapsulation adjusted according to their response. Further, careful consideration of the likelihood of threat from chemical agents must be

made prior to encapsulating patients for whom the encapsulation may have some adverse effects due to excessive accumulation of carbon dioxide.

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APPENDIX

TABLE 5

MEAN (±SD) CHANGE IN BODY TEMPERATURE OVER TIME AND ENCAPSULATION TIME FOR EIGHT SOLDIERS ENCAPSULATED IN THE PROTOTYPE WRAP IN FOUR ENVIRONMENTS WHICH INCLUDED SIMULATED SOLAR RADIATION. THESE DATA ARE FROM A PREVIOUS STUDY (1).

T_a/%rh (°C/%)	$\Delta T_b \cdot \Delta t^{-1}$ (°C•min^{-1})	Encapsulation Time (min)
54.5/17	0.044	38.4
	(0.01)	(5.0)
43.0/58	0.039	49.3
	(0.01)	(8.6)
42.0/16	0.030	61.6
	(0.01)	(14.1)
36/63	0.028	61.8
	(0.01)	(13.2)

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